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SILICON SOLAR CELL PROCESS  
DEVELOPMENT, FABRICATION, AND ANALYSIS

EIGHT QUARTERLY REPORT

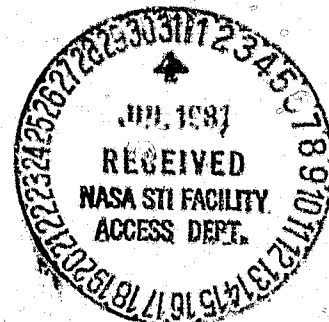
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1 OCTOBER 1980 to 31 DECEMBER 1980

H.I. Yoo, P.A. Iles, and D.C. Leung

JPL CONTRACT NO. 955089

OPTICAL COATING LABORATORY, INC.  
Photoelectronics Division  
15251 E. Don Julian Road  
City of Industry, California 91746



(NASA-CR-164618) SILICON SOLAR CELL PROCESS  
DEVELOPMENT, FABRICATION, AND ANALYSIS  
Quarterly Report, 1 Oct. - 31 Dec. 1980  
(Optical Coating Lab., Inc., City of) 54 p  
HC A04/MF A01 CSCL 10A G3/44 26915

N81-27611

Unclas

"The JPL Low-Cost Silicon Solar Array Project is sponsored by the U.S. Government of Energy and forms part of the Solar Photovoltaic Conversion Program to initiate a major effort toward the development of low-cost solar arrays. This work was performed for the Jet Propulsion Laboratory, California Institute of Technology by agreement between NASA and DOE."

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### **ABSTRACT**

During this reporting period, work included fabrication and characterization of solar cells from HEM, Dendritic Webs, and EFG ribbons. HEM solar cells showed only slight enhancement in cell performance after gettering steps (diffusion glass) were added. Dendritic webs from various growth runs indicated that performance of solar cells made from the webs was not as good as that of the conventional CZ cells. EFG ribbons grown in CO ambient showed significant improvement in silicon quality.

Efforts to passivate grain boundaries (G.B.) by preferential diffusion through G.B. did not result in improvement of sheet quality. Silicon sheets in these tests included SILSO, EFG, and Poly CZ.

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## **I. INTRODUCTION**

The objective of this program is to investigate, develop, and utilize technologies appropriate and necessary for improving the efficiency of solar cells made from various unconventional silicon sheets. During the reporting period, work included fabrication and evaluation of solar cells from HEM (Crystal Systems), dendritic web (Westinghouse), and EFG (Mobil-Tyco). Baseline solar cells were fabricated from HEM wafers after diffusion glass gettering. Baseline and advanced solar cells were fabricated from dendritic webs of various runs. Baseline solar cells were fabricated from EFG (RH) ribbons grown in a furnace with CO-on and CO-off atmosphere and performance results were compared.

Two other process variations (Two step diffusion and low temperature annealing) were applied to some of the sheet silicon. In an effort to passivate grain boundaries, two step diffusion was carried out on materials, such as SILSO, EFG, and Poly CZ wafers. Low temperature annealing was applied on earlier EFG (RH) ribbons in an attempt to restore thermal stress which might be introduced during the ribbon growth. Baseline solar cells were fabricated after these treatments and their performance was compared with that of solar cells that had not undergone these process variations.

## II. TECHNICAL DISCUSSION

### A. HEM Solar Cells

#### 1.0 Solar Cell Fabrication

Baseline solar cells were fabricated on wafers cut from an HEM ingot (4"x 4"x 4", #41-07) with a gettering step added. The gettering step was applied to chemically polished HEM wafers by forming diffusion glasses at 875°C for about an hour (oxygen bubbling through  $\text{POCl}_3$  source). After this step, chemical polishing removed the diffused layer. Baseline solar cells were fabricated on wafers prepared from different positions within the ingot.

Gettering by the diffusion glass was also carried out on vertically cut wafers from a whole HEM ingot (#41-20). Two gettering experiments were made; one on the cleaned saw-cut wafers and the other on the chemically polished wafers. The diffusion glass was formed the same way described above. (See Reference (1) for the detailed description of the HEM process.)

#### 2.0 Solar Cell Performance and Characterization

##### Characteristics Under Illumination

Finished baseline solar cells had  $\text{SiO}_2$  AR coating and about 90% active area with Ti-Pd-Ag metallization. Solar cell parameters, such as  $I_{sc}$ ,  $V_{oc}$ , CFF, and  $n$ , were measured under an AM1 conditions at 28°C test block temperature. Appendix III provides individual parameters of the gettered cells from ingot #41-07. Figure 1 is a plot of a short circuit current density versus wafer position, with and without the gettering step added, indicating improvement of about 0.5  $\text{mA/cm}^2$  by the gettering. Generally, this is similar to results in the Seventh Quarterly Report, however, slight discrepancy in the degree of improvement at various position was noticed.

Appendix IV shows parameters of the baseline cells from ingot #41-20 with the gettering step done on the saw-cut HEM and the chemically polished HEM, respectively. Normalized efficiencies with respect to the CZ control cells are given in Figure 2. The result suggested, compared with the baseline cells without the gettering reported in the Seventh Quarterly Report; 1) Dependence of cell performance on the location is similar, and 2) no significant improvement in cell performance was noticed after the gettering.

### Spectral Response

Absolute spectral response (A/W) was made using a filter wheel set-up. (See Appendix V of reference (2) for the details.) Response versus wavelength of the baseline cells with and without gettering is given in Figure 3 for HEM cells from the top (3-series) and Figure 4 for HEM cells from the bottom (11-series). The HEM cell from the top does not show any significant improvement in the response. However, the cells from the bottom showed noticeable improvement in long wavelength region.

### Minority Carrier Diffusion Length

Minority carrier diffusion length (L) was measured on the same solar cells used to measure spectral response, using the short circuit current method. The L-value of the top HEM cells with and without the gettering was about the same (120 $\mu$ m). Some improvement in L was obtained for the bottom HEM cells after gettering; a gain of 15 $\mu$ m for the gettered cell (#11-7) and 9 $\mu$ m for the cells without gettering.

FIGURE 1

SHORT CIRCUIT CURRENT DENSITY OF HEM BASELINE SOLAR CELLS, WITH AND WITHOUT THE GETTERING,  
AS A FUNCTION OF WAFER POSITION

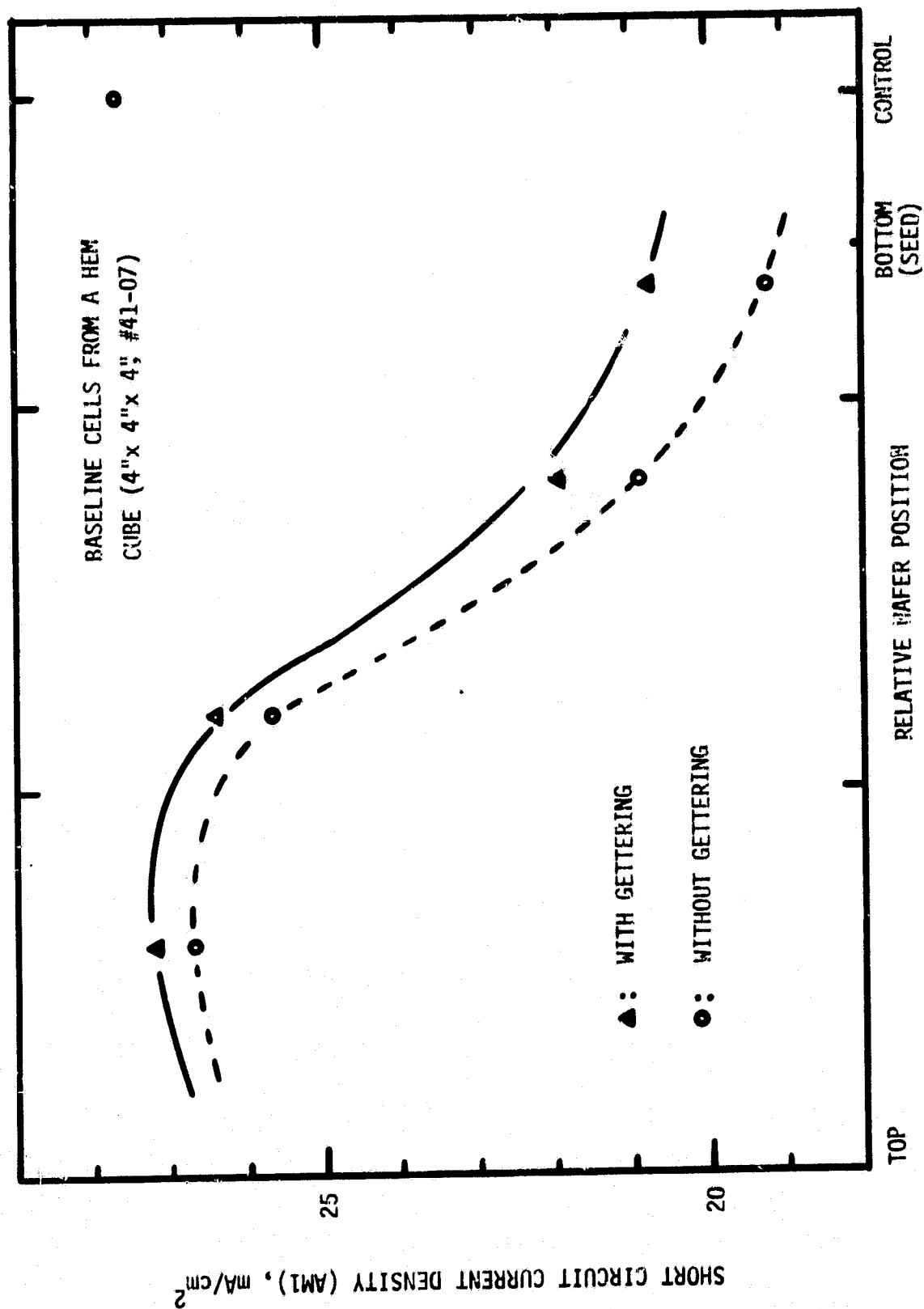
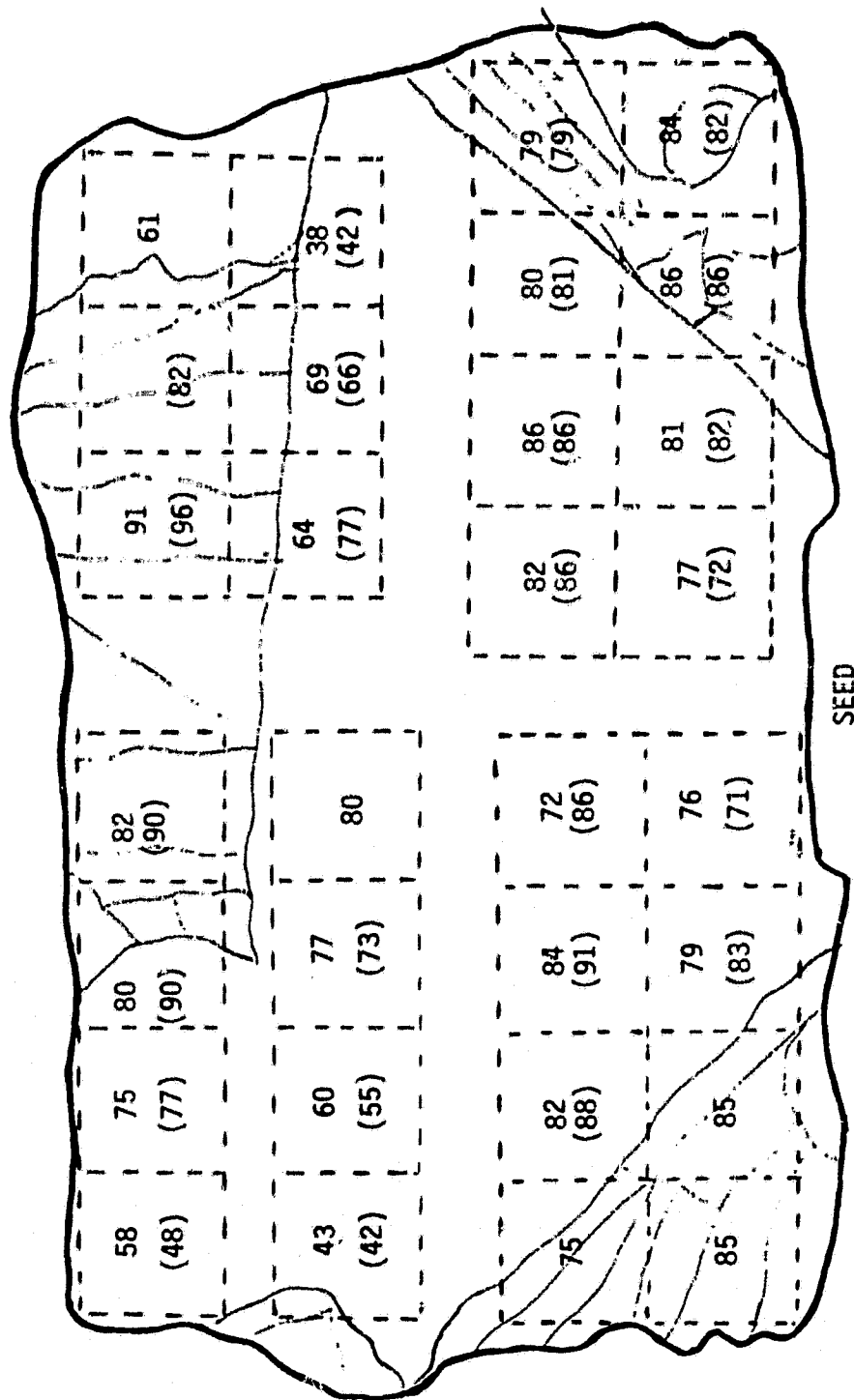


FIGURE 2

EFFICIENCY (NORMALIZED WRT THE CZ CONTROL CELLS) MAPPING OF VERTICALLY

CUT HEM BASELINE CELLS WITH THE GETTERING STEPS ADDED



NOTE: 1) Unit; Percentage

2) Parenthesis numbers for the cells with the gettering step done after the chemical polishing.

FIGURE 3

SPECTRAL RESPONSE OF THE BASELINE SOLAR

CELLS FROM HEM ( TOP SECTION OF NK,OT #41-07)

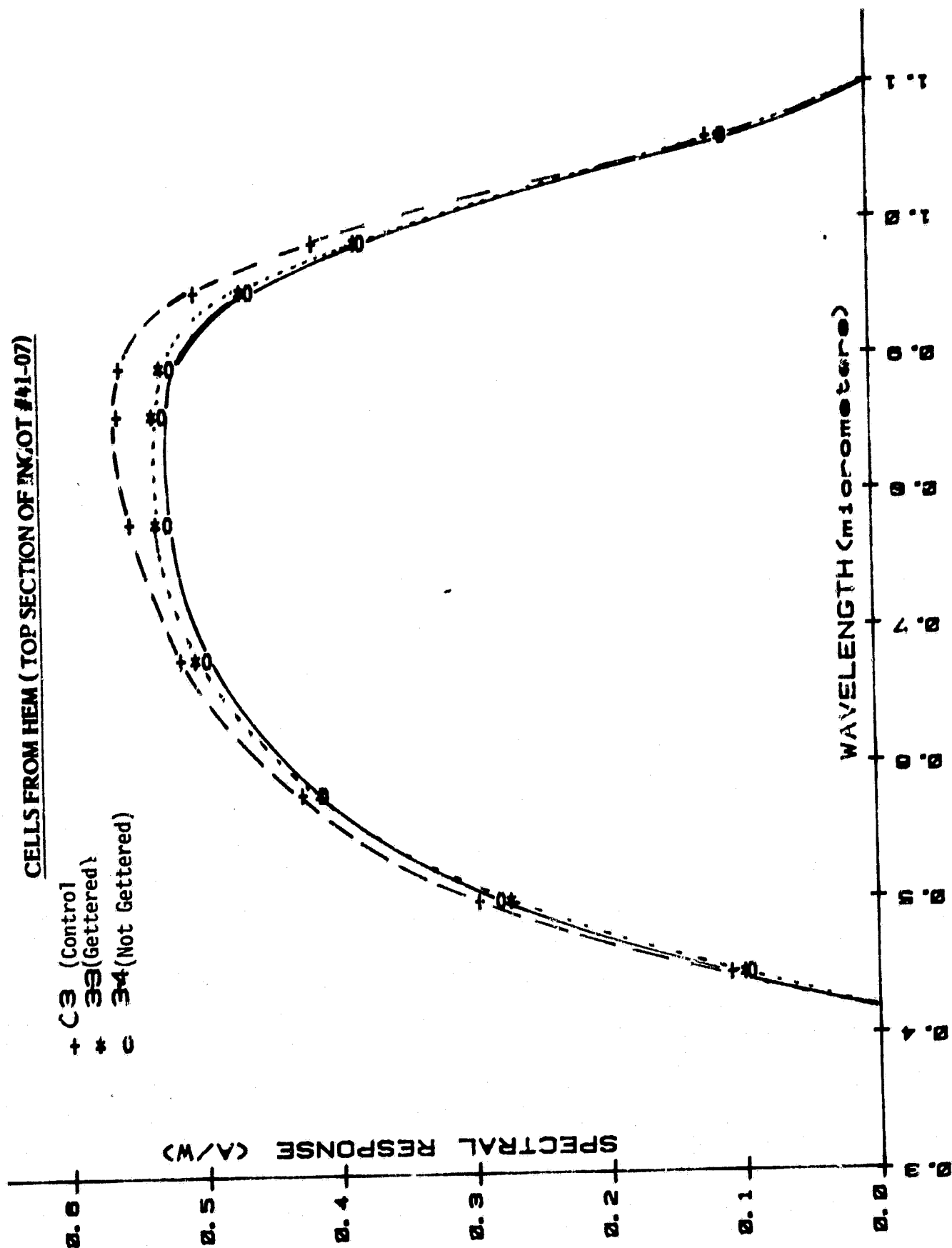
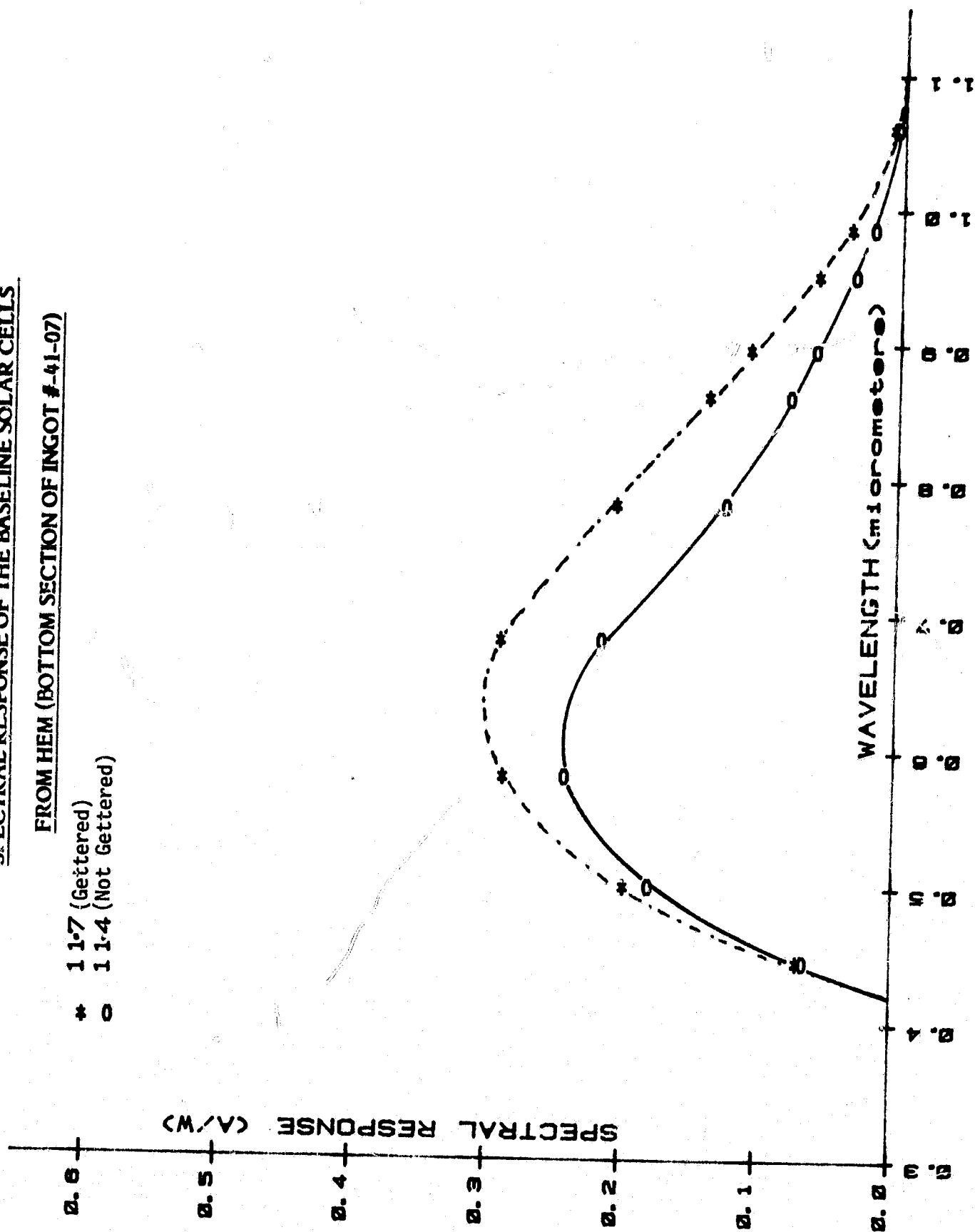


FIGURE 4

SPECTRAL RESPONSE OF THE BASELINE SOLAR CELLS

FROM HEM (BOTTOM SECTION OF INGOT #41-07)

- \* 11.7 (Gettered)
- o 11.4 (Not Gettered)



## **B. Dendritic Web Solar Cells**

### **1.0 Solar Cell Fabrication**

Blank shaping (2x2cm) and removal of the surface deposit (SiO) were carried out using the same method described in Section E of Reference (2). (See Reference (3) for the details of dendritic web process.) Baseline solar cells were fabricated from dendritic webs for various runs; Run 17-1373 (J176-213, 8.5 ohm-cm), 17-1377 (J220-2.6, 3.4 ohm-cm), and 17-1390 (J183-1.5, 9.4 ohm-cm).

Efforts were made to improve the performance by forming a shallow junction, using fine grid lines, BSF and MLAR coating. Baseline solar cells were also fabricated from the same webs and the results were compared. Dendritic webs tested were #17-1387 (J180-2.7, 8 ohm-cm), 17-1388 (J181-3.7, 11 ohm-cm), 17-1389 (J181-3.8, 11 ohm-cm), and 17-1402 (AA009-4.4, 3 ohm-cm).

### **2.0 Solar Cell Performance and Characterization**

#### **Characteristics Under Illumination**

Finished solar cells were tested under AM1 condition at 28°C test block temperature. Individual cell parameters are given in Appendix IV. Table 1 summarizes cell parameters of the baseline process, indicating an average efficiency slightly higher than 11% for dendritic web cells. NOTE: The average efficiency of the CZ control cells (starting substrate resistivity of 1-3 ohm-cm) was about 13%. Lower efficiency of the web cells was mainly due to lower open circuit voltage, caused by the higher starting substrate resistivity of the webs. Short circuit current density of the web cell was lower than the control cells, (by about 1mA/cm<sup>2</sup>) suggesting that the quality of the webs under investigation is not so good as that of conventional CZ silicon.



Cell parameters from the advanced process are summarized in Table 2, showing an average efficiency of 12.5% which is an efficiency improvement of about 1% over the baseline solar cells. Open circuit voltage enhancement by the BSF process does not seem to be as effective as before. The reason for the small improvement in  $V_{oc}$  is not known at present.

### Spectral Response

Absolute spectral response (A/W) was obtained using a filter wheel set-up. The results are plotted in Figure 5 for the baseline solar cells and Figure 6 for the cell from the advanced process. The web cells show response close to those of the CZ control cells, yet showing slightly lower response in the long wavelength region.

### Minority Carrier Diffusion Length

Minority carrier diffusion length ( $L_D$ ) was measured by the filter wheel method using the short circuit current method. Selected samples were measured by illuminating the whole area. The results showed values of about 130um for #6 cell (from web I.D. #17-1373), and 110um for #14 cell (from web I.D. #17-1377), while  $L_D$  of the CZ control cell indicated about 150um.

TABLE 1  
DENDRITIC WEB SOLAR CELL FROM BASELINE PROCESS

		WEB I.D. NO.			CZ CONTROL
		17-1373 $\rho=8.5 \Omega\text{-cm}$	17-1377 $\rho=3.4 \Omega\text{-cm}$	17-1390 $\rho=9.4 \Omega\text{-cm}$	
V <sub>oc</sub> (mV)	AV.	532	534	515	588
	S.D.	530~534	532~536	512~518	584~590
	R	2	2	3	3
J <sub>sc</sub> (mA/cm <sup>2</sup> )	AV.	28.8	28.1	28.6	29.8
	S.D.	0.5	0.3	0.5	0.5
	R	28.3~29.4	27.8~28.4	27.4~29.0	29.3~30.0
CFF (%)	AV.	76	76	75	74
	S.D.	1	1	1	3
	R	75~76	75~76	74~77	70~76
$\eta$ (%)	AV.	11.6	11.4	11.0	13.0
	S.D.	0.1	0.1	0.2	0.6
	R	11.4~11.7	11.3~11.5	10.6~11.3	12.2~13.5

NOTE: 1) 2x2 cm cells under AM1 measured at 28°C test block temperature.

TABLE 2

DENDRITIC WEB SOLAR CELLS FROM ADVANCED PROCESS

			CONTROL CELLS (NO BSF)	
		WEB	WEB	CZ
Voc (mV)	AV.	545	531	581
	S.D.	14	11	-
	R	582-558	514-546	578-582
Jsc (mA/cm <sup>2</sup> )	AV.	29.2	28.1	29.9
	S.D.	0.6	0.5	-
	R	28.5-29.8	27.4-28.8	29.3-30.4
CFF (%)	AV.	79	78	78
	S.D.	1	1	1
	R	78-80	75-79	77-79
$\eta$ (%)	AV.	12.5	11.7	13.5
	S.D.	0.6	0.5	-
	R	11.8-13.0	10.9-12.2	13.2-13.7

NOTE: 1) Measured under AM1 at 28°C test block temperature.

2) Advanced process: SJ+BSF+MLAR

FIGURE 5

SPECTRAL RESPONSE OF THE BASELINE SOLAR

CELLS FROM DENDRITIC WEBS

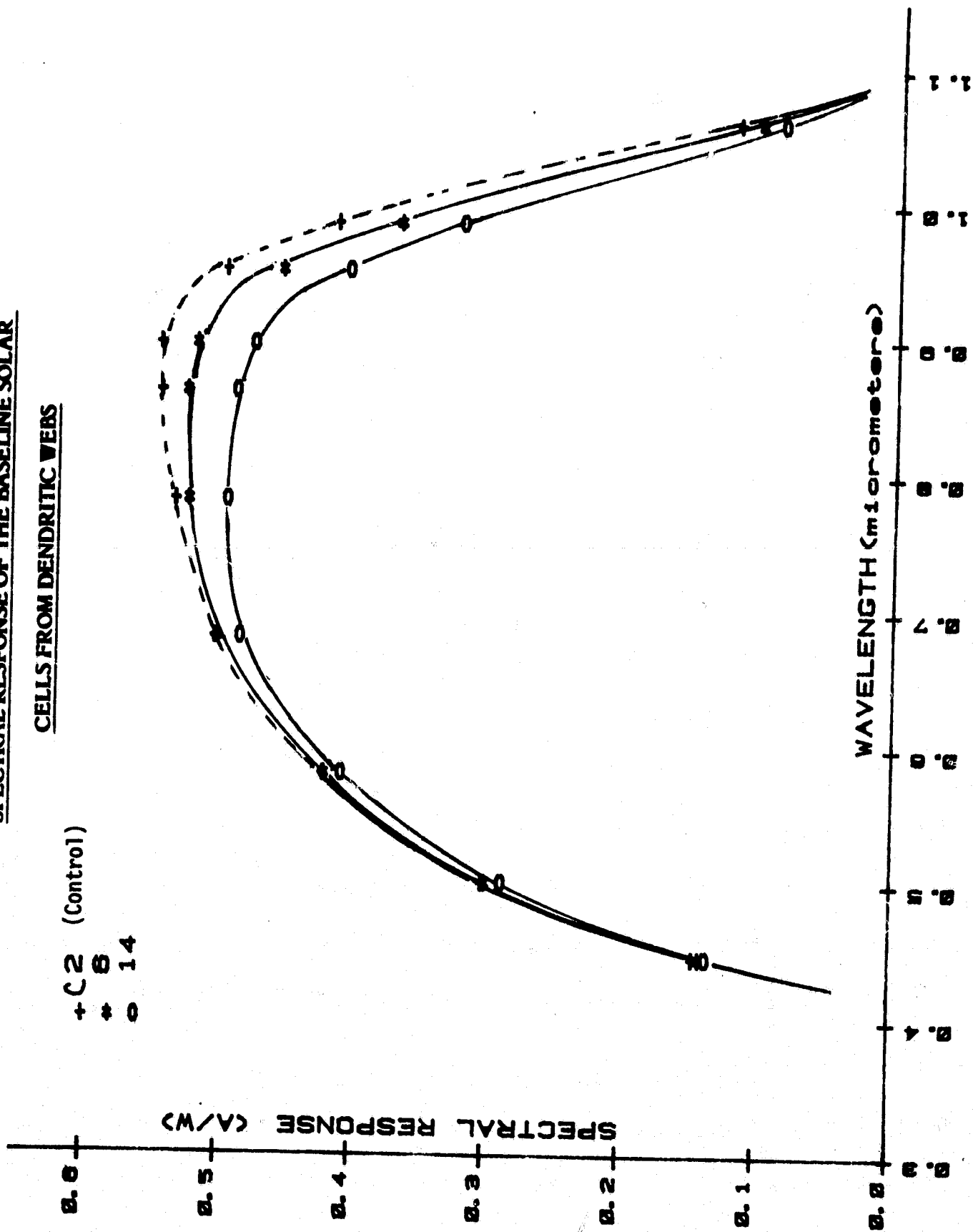
+ C 2 (Control)

\* 8

o 14

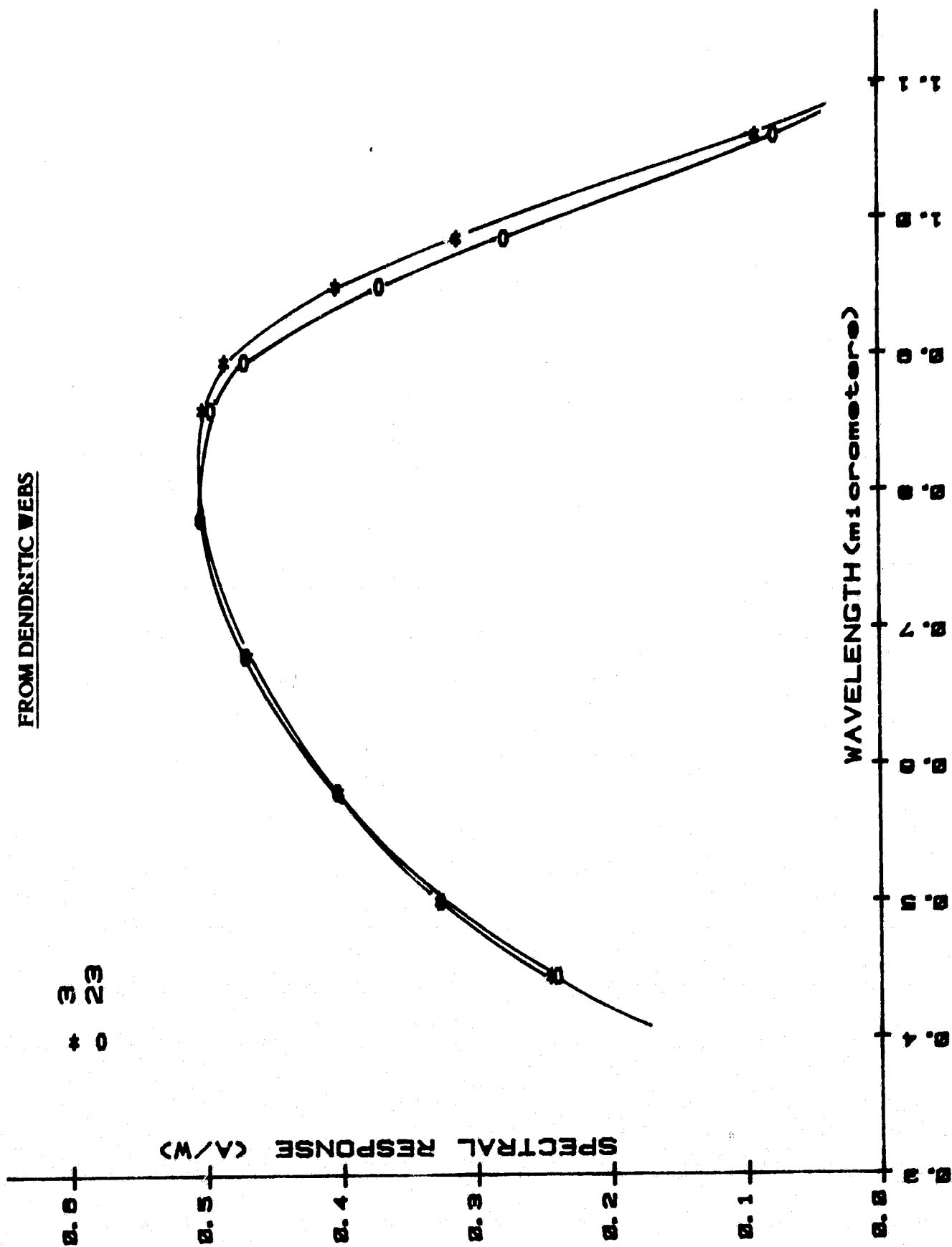
SPECTRAL RESPONSE (A/W)

WAVELENGTH (micrometers)



**FIGURE 6**  
**SPECTRAL RESPONSE OF THE BSF SOLAR CELLS**

**FROM DENDRITIC WEBS**



## **C. EFG Solar Cells**

### **1.0 Solar Cell Fabrication**

EFG ribbons evaluated had been grown in a furnace with CO-off (Run #18-191-0) and Co-on (Run #18-196-1) atmosphere. (Reference (4) provides technical details of the EFG process.) The ribbons were sliced into 2x2cm blanks using a dicing saw and baseline solar cells were fabricated alongside with CZ silicon (control cell) for comparison. (Refer to Appendix IV of Reference (2) for the details of the baseline (standard) process.)

In an effort to reduce potential residual thermal stress before the cell processing, low temperature annealing was tried on earlier EFG ribbons (Run #187-3C series). The EFG blanks were thoroughly cleaned and annealed at 600°C for 48 hours in nitrogen atmosphere. Baseline solar cells were made from both annealed and un-annealed EFG ribbons and the cell performance was compared to see the effect of the annealing.

### **2.0 Solar Cell Performance and Characterization**

#### **Solar Cells From EFG Grown with CO in Ambient**

The products from the baseline process had SiO AR coatings and about 90% active area with Ti-Pd-Ag metallization scheme. Solar cell parameters such as  $J_{sc}$ ,  $V_{oc}$ , CFF, and  $n$  were measured under AM1 conditions at 28°C. Individual cell parameters are given in Appendix V and Table 3 summarizes the results. The EFG cells grown in CO ambient showed improvement in all cell parameters, resulting in an average efficiency of 10.7% AM1 compared with 8.6% of the EFG cells without CO in ambient.

Absolute spectral response (A/W) was made using a filter wheel setup. Response versus wavelength of the baseline solar cells is given in Figure 7 for the EFG

cells with CO-on and Figure 8 for the EFG cells with CO-off. Representative good and bad cells are shown in the figures. The figure suggests that EFG ribbon cells grown in CO atmosphere show higher response in the long wavelength region, indicating higher minority carrier diffusion length with better quality of the silicon.

Minority carrier diffusion length was measured using the short circuit current method for the finished solar cells. Solar cells were selected from short circuit current density information and the results are summarized in Table 4. The Table indicates a range of diffusion length between 35 50um for the EFG with CO-on and 25 35um for the EFG with CO-off. The diffusion length of the CZ control cell was about 140um.

#### **EFG Cells with Low Temperature Annealing**

Baseline solar cells were measured under AM1 without AR coating. Individual cell parameters are given in Appendix V and Table 5 summarizes the results. The table suggests the annealing test did not result in improvement of the sheet quality.

TABLE 3  
AVERAGE CELL PARAMETERS OF EFG RIBBONS WITH AND  
WITHOUT CO IN AMBIENT

	Voc, mV	Jsc mA/cm <sup>2</sup>	CFF, %	, %
WITHOUT CO	540	22.9	70	8.6
WITH CO	567	25.1	76	10.7
CZ CONTROL	582	28.2	78	12.7

NOTE: Baseline Solar Cells (2x2cm) With SiO AR Measured  
at 28°C Under AM1.

TABLE 4  
MINORITY CARRIER DIFFUSION LENGTH LENGTH OF  
SELECTED SOLAR CELLS FROM EFG RIBBONS WITH AND WITHOUT  
CO IN AMBIENT

	EFG WITH CO		EFG WITHOUT CO		CZ CONTROL
CELL I.D.	#8	#10	#7	#3	
DIFFUSION LENGTH ( $\mu$ m)	50	35	35	25	140

NOTE: Diffusion Length (effective) Measured on Whole  
Area (2x2cm) Using Short Circuit Current Method.



TABLE 5

EFG MATERIAL WITH LOW TEMPERATURE ANNEALING (600°C, 30 Hr)

	Voc, mV	J <sub>sc</sub> mA/cm <sup>2</sup>	CFF %	$\eta$ %
NOT ANNEALED	493	13.2	74	4.8
ANNEALED	493	13.3	73	4.7
CZ CONTROL	568	20.1	74	8.5

BASELINE PROCESS ON 2x2 CELLS WITHOUT AR MEASURED AT AM1 AT 28°C. (EFG MATERIAL WITHOUT CO IN THEIR GROWTH)

FIGURE 7

SPECTRAL RESPONSE OF THE BASELINE SOLAR CELLS

FROM EEG WITH CO-ON

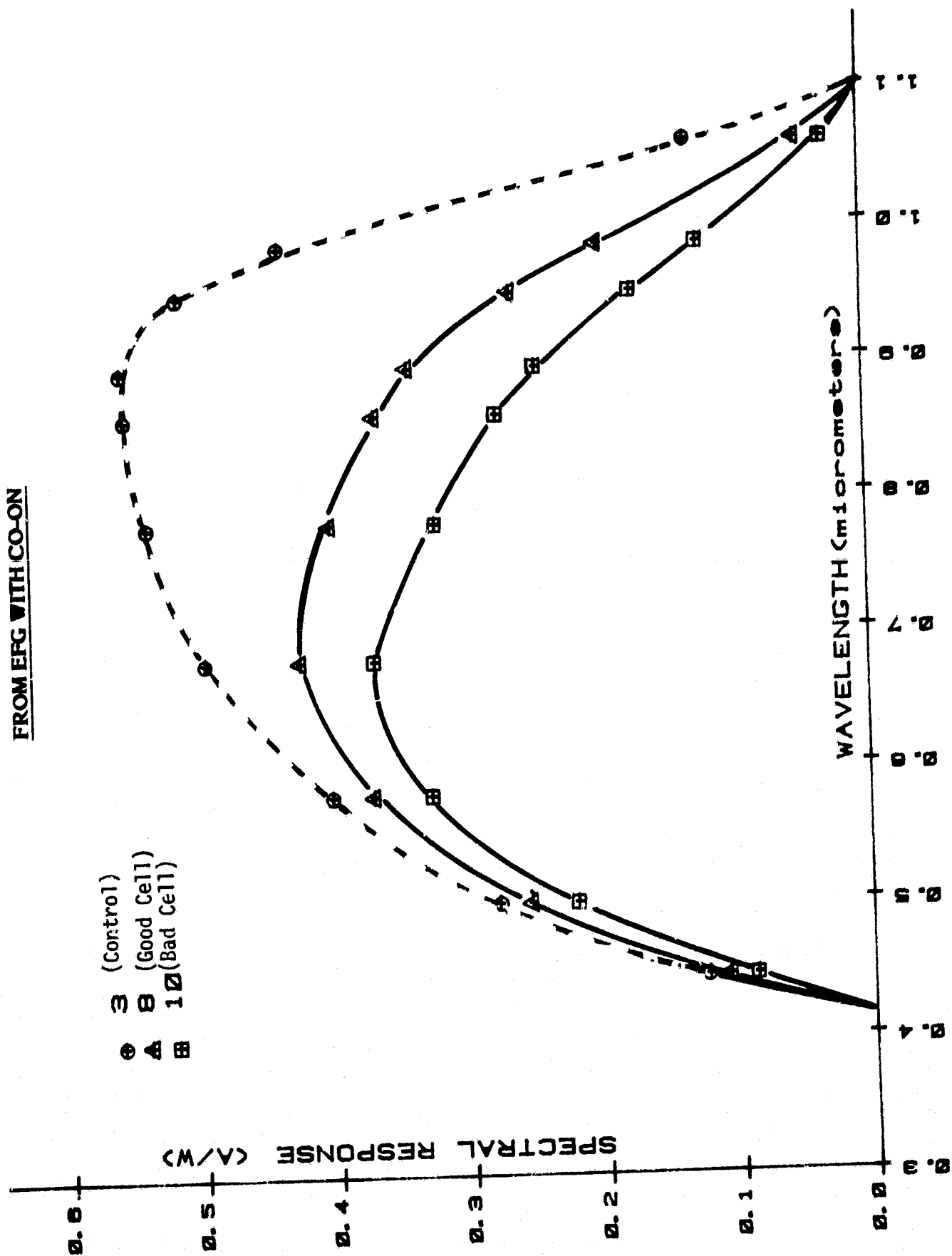
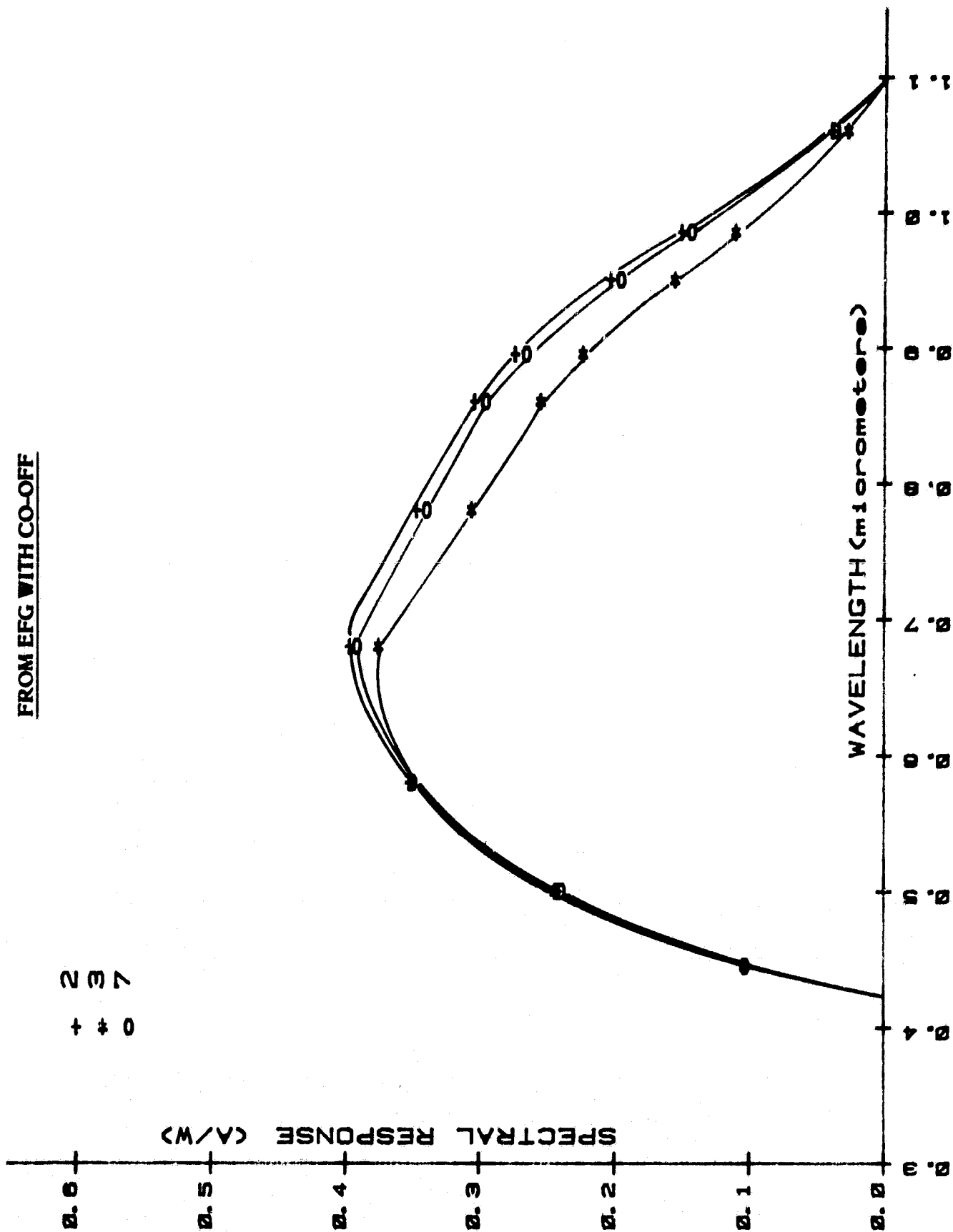


FIGURE 8

SPECTRAL RESPONSE OF THE BASELINE SOLAR CELLS

FROM EFG WITH CO-OFF



## **D. Solar Cells From Two Step Diffusion**

### **1.0 Solar Cell Fabrication**

Since significant improvement in solar cell performance, specifically short circuit current, was reported (5) at the 1980 European Photovoltaic Solar Energy Conference by utilizing two step diffusion, an experiment was carried out to try and reproduce the tests. Silicon sheets under test were SILSO (Wacker), EFG, and poly silicon from CZ growth. The first step diffusion included 9 hours of  $\text{POCl}_3$  diffusion at  $750^\circ\text{C}$ , it was hoped that preferential diffusion at grain boundaries would occur at this stage. Normal diffusion at  $875^\circ\text{C}$  followed thereafter and baseline solar cells (2x2cm) were fabricated. Half of the samples were inserted during the second stage diffusion (normal  $875^\circ\text{C}$  diffusion), serving as control cells, to compare the results of the cells with two step diffusion. No AR coating was applied to these cells.

### **2.0 Solar Cell Performance**

The solar cells were tested under AM1 conditions (no AR coating). Individual cell parameters are given in Appendix VI. The cell data indicated that none of the silicon sheets showed improvements in solar cell parameters. Table 6 shows a comparison of short circuit current density of the solar cells with and without the two step diffusion.

$J_{sc}$  of poly CZ and SILSO cells stayed about the same, while EFG cells showed reduction in  $J_{sc}$  after the first step diffusion.

TABLE 6

AVERAGE SHORT CIRCUIT CURRENT DENSITY ( $J_{sc}$ , mA/cm<sup>2</sup>)  
FOR TWO STEP DIFFUSION PROCESS (750°C, 9Hr. in POCl<sub>3</sub>)

	EFG	POLY HAMCO	SILSO
No 2 Step Diffusion	17.9	22.1	22.4
2 Step DIFFUSION	15.3	22.1	22.3

Jsc of Control: 23.4

Baseline process on 2x2 cells without AR, measured at  
AMI, 28°C. (EFG material without CO in growth)

### III. CONCLUSIONS AND RECOMMENDATIONS

The conclusions and recommendations reached after processing and evaluation of the sheets are as follows:

#### HEM

- o Gettering by diffusion glass on two ingots resulted in only a slight improvement in cell efficiency, the degree of enhancement depending on the position of the wafers within the ingots.
- o Gettering results suggest that microscopic analysis of structural defects and impurities, especially inclusions or precipitates, is necessary to identify the potential areas of degrading silicon sheet quality.

#### Dendritic Web

- o Baseline solar cells from dendritic webs of various runs suggested that quality of the webs under investigation was not as good as the conventional CZ silicon, and was slightly sooner than that of the better web samples tested earlier.

#### EFG

- o EFG ribbons grown with CO in the ambient showed significant improvement in silicon quality, resulting in an average baseline efficiency of 10.7% AM1 compared with 8.6% of the EFG cells without CO in the ambient.
- o Low temperature annealing prior to the cell process did not result in improvement in silicon quality.

#### Two Step Diffusion Process

- o Efforts to passivate grain boundary by preferential diffusion, 9 hours of  $\text{POCl}_3$  diffusion at  $750^\circ\text{C}$ , did not result in enhancement of the quality of silicon sheets (SILSO, EFG, or Poly CZ).

#### **IV. WORK PLAN STATUS**

The following silicon sheets are expected for processing and evaluation during the next period.

- o Three dimensional evaluation of large HEM ingots.
- o Fabrication of solar cells from the pre-characterized dendritic webs.
- o Fabrication and performance comparison of EFG ribbons grown in CO<sub>2</sub>-on and CO<sub>2</sub>-off atmosphere.

**V. REFERENCES**

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4. F.V. Wald, et.al., "Large Area Silicon Sheet by EFG". JPL Contract No. 954355, Technical Reports for the LSA Project, Mobil-Tyco.
5. F. Ferraris and F.C. Maticotta, "Optimized Diffusion Parameters for Cells Made by Columnar Silicon". Proc. of European Photovoltaic Solar Energy Conf., to be published, October 1980.



**APPENDIX I**  
**TIME SCHEDULE**

### TIME SCHEDULE

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**APPENDIX II**  
**ABBREVIATIONS**

$V_{OC}$ : Open Circuit Voltage  
 $I_{SC}$ : Short Circuit Current  
 $J_{SC}$ : Short Circuit Current Density  
 $I_{SCR}$ : Short Circuit Current (Red Response) at Wavelength Above  $\sim .6 \mu m$   
 $I_{SCB}$ : Short Circuit Current (Blue Response) at Wavelength Below  $\sim .6 \mu m$   
CFF: Curve Fill Factor  
 $\eta$ : Solar Cell Conversion Efficiency  
L: Minority Carrier Diffusion Length (D.L.)  
 $I_{MAX}$ : Current at Maximum Power Point  
 $V_{MAX}$ : Voltage at Maximum Power Point  
 $P_{MAX}$ : Maximum Power Point  
BSF: Back Surface Field  
BSR: Back Surface Reflector  
 $V_B$ : Bias Voltage  
 $I_O$ : Diode Saturation Current  
HEM: Heat Exchanger Method  
EFG: Edge Defined Film-Fed Growth  
SOC: Silicon on Ceramic  
RTR: Ribbon-to-Ribbon  
SPV: Surface Photovoltage  
MLAR: Multi-Layer Anti-Reflective  
 $R_s$ : Series Resistance

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**APPENDIX III**  
**ELECTRICAL DATA SHEETS FOR HEM SOLAR CELLS**

# SOLAR CELL ELECTRICAL DATA

CELL DESCRIPTION:

Baseline Solar Cells from a HEM Cube (#41-07)

TEST CONDITION:

Gettering by diffusion glass after the chemical polishing.

TEMPERATURE:

AM1 with SiO AR Coating.

28°C Test Block

NO.	V <sub>OC</sub> mV	J <sub>SC</sub> mA/cm <sup>2</sup>	P <sub>Max</sub> mW	CFF %	n %	AREA cm <sup>2</sup>
3-1	574	22.0		73	11.3	3.9
3-3	576	22.5		73	11.6	"
3-5	572	26.9		73	11.2	"
3-7	582	27.4		78	12.4	"
3-9	580	22.0		77	12.1	"
6-1	580	27.4		76	12.1	"
6-3	572	26.0		75	11.1	"
6-5	568	24.6		74	11.2	"
6-7	578	26.4		77	11.7	"
6-21	566	25.4		74	10.6	"
9-1	548	22.6		77	9.5	"
9-3	546	22.5		77	9.4	"
9-5	544	22.5		75	9.2	"
9-7	544	22.6		75	9.3	"
9-21	522	19.2		78	7.8	"
11-1	518	19.6		75	7.6	"
11-7	532	23.1		74	9.1	"
11-11	520	20.7		74	8.0	"
11-13	510	19.6		73	7.3	"
12-27	508	18.7		73	7.0	"

(Continued)

## SOLAR CELL ELECTRICAL DATA

CELL DESCRIPTION: Baseline Solar Cells from a HEM Cube (#41-07)  
 TEST CONDITION: Control Cells for Gettering Test  
 TEMPERATURE: AMI with SiO AR Coating  
 280C Test Block

NO.	V <sub>OC</sub>	J <sub>SC</sub>	P <sub>Max</sub>	CFF	n	AREA
	mV	mA/cm <sup>2</sup>	mW	%	%	cm <sup>2</sup>
3-2	576	25.9		78	11.6	3.9
3-4	576	27.0		74	11.5	"
3-6	576	26.9		78	12.0	"
3-8	578	26.9		77	12.0	"
6-2	574	25.9		74	11.1	"
6-4	576	25.5		76	11.2	"
6-6	576	26.9		78	12.0	"
6-20	566	24.4		76	10.5	"
6-22	576	26.4		78	11.8	"
9-2	540	21.0		77	8.8	"
9-4	552	22.6		77	9.6	"
9-6	536	20.0		76	8.2	"
9-20	538	21.1		77	8.7	"
9-22	532	20.0		74	7.9	"
11-4	512	19.7		71	7.2	"
12-28	508	18.7		73	7.0	"
		CZ control cells (Down)				
C-1	576	27.5		77	12.2	3.9
C-2	574	27.4		78	12.2	"
C-3	574	28.0		76	12.1	"

# SOLAR CELL ELECTRICAL DATA

CELL DESCRIPTION: Baseline Solar Cells from a HEM Ingot (Vertically Cut)  
 Gettering by Diffusion Glass before the Chemical Polishing  
 TEST CONDITION: AM1 with SiO AR Coating  
 TEMPERATURE: 28°C Test Block

NO.	V <sub>OC</sub>	J <sub>SC</sub>	P <sub>Max</sub>	CFF	n	AREA
	mV	mA/cm <sup>2</sup>	mW	%	%	cm <sup>2</sup>
1	516	19.6		74	7.5	3.9
2	544	24.2		75	9.8	"
3	560	26.8		69	10.4	"
4	560	26.2		73	10.7	"
5	572	27.4		75	11.8	"
6	538	25.2		55	7.5	"
7	524	20.6		73	7.9	"
8	480	15.6		75	5.6	"
9	526	19.5		76	7.8	"
10	548	23.7		77	10.0	"
11	554	24.7		76	10.4	"
12	540	24.2		64	8.3	"
13	536	22.1		75	8.9	"
14	476	15.0		68	4.9	"
15	538	24.4		74	9.7	"
16	568	26.4		72	10.7	"
17	564	26.3		73	10.9	"
18	552	25.8		66	9.4	"
19	558	25.8		76	10.6	"
20	564	26.3		75	11.2	"
21	568	26.8		68	10.4	"
22	552	25.4		74	10.3	"



### SOLAR CELL ELECTRICAL DATA

[illegible]

# SOLAR CELL ELECTRICAL DATA

CELL DESCRIPTION: Baseline Solar Cells from a HEM Ingot (Vertically Cut)  
Gettering by diffusion glass after the Chemical Polishing  
 TEST CONDITION: AM1 with AR Coating  
 TEMPERATURE: 28°C Test Block

NO.	V <sub>OC</sub> mV	J <sub>SC</sub> mA/cm <sup>2</sup>	P <sub>Max</sub> mW	CFF %	n %	AREA cm <sup>2</sup>
31	504	19.5		61	6.0	3.9
32	546	24.8		71	9.6	"
33	568	26.7		74	11.2	"
34	562	26.3		76	11.2	"
35	574	26.9		78	12.0	"
36	554	25.2		74	10.3	"
37	470	20.6		36	3.5	"
38	478	15.5		71	5.2	"
39	516	20.8		65	6.9	"
40	546	22.8		73	9.1	"
41	530	24.4		54	6.9	"
42	546	24.2		72	9.6	"
43	532	21.7		71	8.2	"
44	478	15.1		71	5.2	"
46	568	26.4		73	11.0	"
47	566	26.8		75	11.4	"
48	560	25.8		75	10.8	"
49	560	25.8		74	10.7	"
50	560	25.8		74	10.7	"
51	562	26.9		67	10.1	"
52	548	24.9		73	9.9	"
53	546	26.8		57	8.3	"

(Continued)

### SOLAR CELL ELECTRICAL DATA

CELL DESCRIPTION:	Baseline Solar Cells from a HEM Ingot (Vertically Cut)
	Gettering by Diffusion Glass after the Chemical Polishing
TEST CONDITION:	AM1 With AR Coating
TEMPERATURE:	28°C Test Block

[illegible]

**APPENDIX IV**  
**ELECTRICAL DATA SHEETS FOR DENDRITIC WEB SOLAR CELLS**

# SOLAR CELL ELECTRICAL DATA

CELL DESCRIPTION: Dendritic Web Solar Cells (2x2cm), Baseline Process

TEST CONDITION: SiO<sub>2</sub> AR Coating

TEMPERATURE: AM1  
28°C Test Block 11/80

NO.	V <sub>OC</sub> mV	J <sub>SC</sub> mA/cm <sup>2</sup>	P <sub>Max</sub> mW	CFF %	n %	AREA cm <sup>2</sup>
1	534	28.5		76	11.6	4.0
4	532	28.9		75	11.5	"
5	530	28.3		76	11.4	"
6	532	29.4		75	11.7	"
	Above	WEB ID # 117-1373 (≈ 8 ohm-cm)				
12	534	27.8		76	11.3	4.0
14	532	28.4		75	11.3	"
15	536	28.3		76	11.5	"
16	534	28.0		76	11.4	"
	Above	WEB ID # 117-1377 (≈ 4 ohm-cm)				
21	512	27.4		76	10.6	4.0
22	518	28.9		74	11.1	"
23	512	28.9		74	11.0	"
25	518	28.8		75	11.2	"
26	512	29.0		74	11.0	"
27	514	28.3		75	10.9	"
28	518	28.8		76	11.3	"
29	514	28.4		77	11.2	"
	Above	WEB ID # 117-1390 (≈ 9 ohm-cm)				

### SOLAR CELL ELECTRICAL DATA

**TEMPERATURE:**

11/80

[illegible]

ORIGINAL PAGE IS  
OF POOR QUALITY

## Dendritic Web Solar Cells, SJ+BSF Process

### With MLAR Coating

## AM1

29. C. Test Block

11/20

[illegible]

## SOLAR CELL ELECTRICAL DATA

11/80

[illegible]



**APPENDIX V**  
**ELECTRICAL DATA SHEETS FOR EFG SOLAR CELLS**

# SOLAR CELL ELECTRICAL DATA

CELL DESCRIPTION: Baseline Cells From EFG Grown CO-off And CO-on Atmosphere With AR.  
 TEST CONDITION: AM1  
 TEMPERATURE: 28°C Test Block Temperature.

NO.	V <sub>OC</sub> mV	J <sub>SC</sub> A/cm <sup>2</sup>	P <sub>max</sub> mW	EFF %	n %	AREA cm <sup>2</sup>
EFG with CO-off						
2	538	23.5		64	8.1	4
3	540	22.2		77	9.2	"
7	542	23.0		69	8.5	"
EFG with CO-on						
8	572	26.0		76	11.4	4
10	558	23.4		77	10.0	"
12	558	24.6		76	10.5	"
13	574	25.6		73	10.7	"
15	574	25.9		75	11.1	"
C2 control cells						
C1	586	28.4		78	12.9	4
C2	580	27.5		78	12.4	"
C3	580	28.5		78	12.9	"
C4	580	28.4		76	12.5	"

# SOLAR CELL ELECTRICAL DATA

CELL DESCRIPTION: EFG Baseline Cells (2x2cm) with Low Temperature Annealing  
 TEST CONDITION: No AR  
 TEMPERATURE: AM1  
 28°C Test Block Temperature

NO.	V <sub>OC</sub> mV	J <sub>SC</sub> mA/cm <sup>2</sup>	P <sub>Max</sub> mW	CFF %	η %	AREA cm <sup>2</sup>
2	492	13.3		75	4.9	4
4	498	13.4		76	5.0	"
8	494	13.4		75	4.9	"
10	488	13.3		64	4.1	"
12	490	13.2		72	4.6	"
16	498	13.2		76	5.0	"
24	484	12.7		72	4.5	"
28	500	13.9		74	5.1	"
30	500	13.7		74	5.1	"
34	492	12.8		76	4.8	"
36	490	13.4		68	4.4	"
38	490	12.8		69	4.3	"
EFG control cell (Not annealed)						
1	500	13.7		76	5.2	4
3	486	12.2		77	4.6	"
5	488	12.7		72	4.5	"
7	486	12.3		78	4.6	"
9	500	13.7		75	5.1	"
11	496	13.2		75	4.9	"

187-3C-218  
 187-3C-222  
 187-3C-228  
 187-3C-240  
 187-3C-241  
 187-3C-218  
 187-3C-222

# SOLAR CELL ELECTRICAL DATA (CONTINUED)

CELL DESCRIPTION: EFG Baseline Cells (2x2cm) with Low Temperature Annealing  
N6 AR

TEST CONDITION: AM1

TEMPERATURE: 28°C Test Block Temperature

NO.	V <sub>OC</sub>	J <sub>SC</sub>	P <sub>Max</sub>	CFF	n	AREA
	mV	mA/cm <sup>2</sup>	mW	%	%	cm <sup>2</sup>
13	484	12.8		73	4.5	4
17	510	14.3		77	5.6	"
19	500	13.2		75	5.0	"
23	502	13.9		74	5.2	"
25	490	12.7		74	4.6	"
27	478	12.8		63	3.9	"
29	494	18.3		75	5.0	"
33	496	13.7		75	6.1	"
37	492	12.7		76	4.7	"
C2 control cells						
C3	568	20.0		74	8.4	4
C4	568	20.2		74	8.5	"

187-3C 187-3C-228  
187-3C-240 187-3C-241

**APPENDIX VI**

**ELECTRICAL DATA SHEETS FOR SOLAR CELLS FROM TWO STEP DIFFUSION**

# CELL TEST ELECTRICAL DATA

CELL DESCRIPTION: EFG Cells (2x2cm) with Two Step Diffusion  
 TEST CONDITION: No AR  
 TEMPERATURE: AMO  
 28°C Test Block Temperature

NO.	V <sub>OC</sub> mV	J <sub>SC</sub> mA/cm <sup>2</sup>	P <sub>Mix</sub> mW	CFF %	n %	AREA cm <sup>2</sup>
8	464	14.8		67	3.4	4
12	470	14.8		73	3.7	"
14	468	14.3		69	3.5	"
18	476	16.1		70	4.0	"
20	476	16.2		64	3.7	"
22	476	15.7		69	3.8	"
30	472	15.1		70	3.7	"
EFG control cells (No two step diffusion)						
3	506	19.0		74	5.3	4
7	494	17.7		71	4.6	"
9	498	18.7		66	4.6	"
17	498	17.6		69	4.5	"
19	502	18.6		68	4.7	"
25	490	17.6		72	4.6	"
27	480	15.7		70	3.9	"
29	500	18.1		65	4.4	"

### PHYSICAL DATA

CELL DESCRIPTION: SILSO Cells (2x2cm) with Two Step Diffusion  
No AR  
TEST CONDITION: AM1  
TEMPERATURE: 28°C Test Block Temperature

NO.	$V_{OC}$ mV	$J_{SC}$ mA/cm <sup>2</sup>	$P_{Max}$ mW	CFF %	$\eta$ %	AREA cm <sup>2</sup>
6	520	21.6		73	6.1	4
8	532	22.0		76	6.6	"
10	538	22.0		75	6.6	"
12	540	22.6		74	6.7	"
14	538	22.5		77	6.9	"
18	538	23.0		64	5.8	"
Wacker control cells (no two step diffusion)						
5	528	22.1		75	6.5	4
13	540	22.5		75	6.7	"
15	542	22.5		76	6.9	"
17	540	22.6		76	6.9	"